# Memorandum

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Subject: **Supplemental Technical Memorandum to CalSim-II Model Sensitivity Analysis Study, October 2005**

## 1 Introduction

DWR Bay-Delta Office completed a sensitivity analysis study for CalSim-II model in 2005 in response to the issues raised in the review of the 2002 “State Water Project Delivery Reliability Report”, and the recommendations in the peer review report sponsored by the CALFED Science Program in December 2003. There were three objectives of the CalSim-II Sensitivity Analysis Study:

- to examine the behavior of the SWP-CVP system performance in response to variations in selected input parameters within CalSim-II
- to help SWP contractors and others understand the impact of key assumptions within CalSim-II on the SWP delivery capability
- to aid CalSim-II modelers for prioritizing future model development activities on the basis of sensitivities of input parameters

In that study, twenty-one CalSim-II model input parameters and their associated ranges of variations were selected for the analysis; twenty-two key output variables that cover various aspects of a simulation outcome were selected for the model response evaluation; and two performance measures: Sensitivity Index (SI) and Elasticity Index (EI) were defined to quantify the model sensitivity with respect to the model input parameter changes.

A technical memorandum report - *CalSim-II Model Sensitivity Analysis Study* was developed and released in October of 2005. The report documented the CalSim-II model sensitivity analysis objectives, methodology, and summary of results. A number of selected input parameters that significantly affect the SWP were also discussed in the report to show how the SWP deliveries and other key model outputs relevant to SWP operations respond to the changes in model inputs.

In order to further assist SWP contractors and other interested parties to evaluate the impact of model input parameters on SWP deliveries, this supplemental technical memorandum summarizes sensitivities of SWP deliveries (SWP Delta Delivery, SWP NOD Delivery, and Article 21 Delivery) with respect to a larger subset of input parameters analyzed.

*CalSim-II Model Sensitivity Analysis Study* released in October of 2005 is referred to as the *Main Report* in this supplemental technical memorandum. All terminology and performance measures used in this memorandum are directly from the *Main Report*. The additional discussions here are also based on the modeling results in the *Main Report*. It is expected that readers of this supplemental technical memorandum have had certain familiarity with the *Main Report*.

This supplemental technical memorandum consists of four sections. Section 1 (this section) is a general background and a brief introduction of this memorandum; Section 2 briefly reiterates some definitions and terminologies that were already introduced in the *Main Report* and are inherited by this memorandum; Section 3 contains the more detailed discussions on the impact of each of selected input parameters on SWP deliveries; and Section 4 demonstrates alternative ways of presenting the study results.

## 2 Definitions and Terminologies

This section briefly reiterates some definitions and terminologies that were introduced in the *Main Report* and are inherited by this memorandum.

Two performance measures – Sensitivity Index (SI) and Elasticity Index (EI) – are used to quantify the model output sensitivity with respect to a given model input parameter. The SI is a first-order derivative of a model output variable with respect to an input parameter. It can be used to measure the magnitude of change in an output variable per unit change in the magnitude of an input parameter from its base value. The EI is a dimensionless expression of sensitivity that measures the relative change in an output variable to a relative change in an input parameter. As an example, assuming SI = 0.5 and EI = 0.25 for the output variable of total Delta outflow with respect to the input parameter of Oroville inflow, means that for one thousand acre-feet (TAF) increase in Oroville inflow, total Delta outflow increases by 0.5 TAF; and for one percent increase in Oroville inflow, total Delta outflow increases by 0.25 percent, respectively. These two performance measures, SI and EI, were derived and discussed in more detail in Chapter 2 of the *Main Report*.

All selected input parameters are discussed one at a time in order to show how the SWP deliveries (SWP Delta Delivery, SWP NOD Delivery, and Article 21 Delivery) respond to the changes in model inputs. In CalSim-II, SWP Delta Delivery is defined as SWP Table A deliveries to South-of-Delta (SOD) plus deliveries to North Bay (Solano and Napa Counties) contractors. SWP NOD delivery is defined as the sum of deliveries to the Settlement Contractors in Feather River Service Area (FRSA) and Table A deliveries to Butte County and Yuba City.

SIs and EIs of the three types of SWP deliveries with respect to selected model input parameters for the analysis are computed based on their 73-year average annual values and are summarized in Table 1, which is excerpted from both Tables 2 and 3 in the *Main Report*. The left-most column of the table lists the input parameters analyzed and the top row of the table lists the types of SWP deliveries. SIs and EIs values are listed in the separate sub-columns under each output variables. The color shadings indicate different levels of sensitivity; red represents high sensitivity ($|SI| > 0.2$); yellow represents medium sensitivity ($0.1 <= |SI| <= 0.2$); and white represents low sensitivity ($|SI| < 0.1$). Reader should keep in perspective the degree of perturbation made for each input parameter investigated in this study when drawing any conclusions from the computed sensitivities. Note that there are no SI values computed for input parameters of X2, ANN, SWP Delivery-Carryover Curve, and SWP San Luis Rule-curve since relevant water volume changes cannot be properly defined and computed. All discussions are based on the average SIs and EIs except for those SIs and EIs that are non-monotonic functions (see Chapter 2 in the *Main Report*) of the corresponding input parameters, in which case individual EI and SI should be evaluated.

As stated in the *Main Report*, in the real world, SI may be more meaningful for water planners, operators, water users, and managers because of its intuitive character. They may propose different demand levels, such as agricultural and municipal and industrial (M & I) practices or water operations for more water

**Table 1**
**Summary of Sensitivity Index (SI) and Elasticity Index (EI)**

| Model Input Parameters | | | Model Output Variables | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | SWP Delta Delivery | | SWP NOD Delivery | | Article 21 Delivery | |
| | | | 1 | | 2 | | 3 | |
| Name | Row # | Range | EI | SI | EI | SI | EI | SI |
| Shasta Inflow | 1 | -5% | 0.10 | 0.05 | 0.00 | 0.00 | 0.52 | 0.01 |
| | | +5% | 0.05 | 0.03 | 0.00 | 0.00 | 0.16 | 0.00 |
| | | Average | 0.08 | 0.04 | 0.00 | 0.00 | 0.34 | 0.01 |
| Oroville inflow | 2 | -5% | 0.28 | 0.21 | 0.01 | 0.00 | -0.14 | -0.01 |
| | | +5% | 0.25 | 0.19 | 0.01 | 0.00 | -0.88 | -0.03 |
| | | Average | 0.26 | 0.20 | 0.01 | 0.00 | -0.51 | -0.02 |
| Yuba inflow | 3 | -5% | 0.06 | 0.11 | 0.00 | 0.00 | -0.00 | -0.00 |
| | | +5% | 0.07 | 0.12 | 0.00 | 0.00 | 0.18 | 0.01 |
| | | Average | 0.07 | 0.12 | 0.00 | 0.00 | | |
| Folsom inflow | 4 | -5% | 0.05 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 |
| | | +5% | 0.06 | 0.13 | 0.00 | 0.00 | 0.31 | 0.04 |
| | | Average | 0.05 | 0.12 | 0.00 | 0.00 | 0.16 | 0.02 |
| Projected Land Use | 5 | -5% | -0.10 | -0.05 | 0.26 | 0.03 | -0.16 | -0.00 |
| | | +5% | -0.08 | -0.04 | 0.09 | 0.01 | -0.74 | -0.02 |
| | | Average | -0.09 | -0.04 | 0.17 | 0.02 | -0.45 | -0.01 |
| SWP Delivery-Carryover Curve | 6 | -20% | -0.12 | | -0.00 | | 0.62 | |
| | | +20% | -0.17 | | -0.01 | | 0.80 | |
| | | Average | -0.15 | | -0.01 | | 0.71 | |
| SWP San Luis Rule Curve | 7 | -10% | 0.01 | | 0.00 | | 0.46 | |
| | | +10% | -0.01 | | -0.00 | | 0.47 | |
| | | Average | | | | | 0.46 | |
| SWP Table A Demand | 8 | -29% | 0.74 | 0.63 | -0.01 | -0.00 | -3.49 | -0.15 |
| | | -14% | 0.63 | 0.54 | -0.01 | -0.00 | -3.06 | -0.13 |
| | | 18% | 0.39 | 0.33 | -0.01 | -0.00 | -1.76 | -0.08 |
| | | 29% | 0.44 | 0.37 | -0.01 | -0.00 | -2.15 | -0.09 |
| | | Average | 0.55 | 0.47 | -0.01 | -0.00 | -2.62 | -0.11 |
| Article 21 Demand | 9 | 199% | -0.00 | -0.02 | -0.00 | -0.00 | 0.24 | 0.27 |
| | | 348% | -0.00 | -0.00 | -0.00 | -0.00 | 0.16 | 0.18 |
| | | 497% | -0.00 | -0.00 | -0.00 | -0.00 | 0.12 | 0.13 |
| | | 646% | -0.00 | -0.00 | -0.00 | -0.00 | 0.10 | 0.11 |
| | | Average | -0.00 | -0.01 | -0.00 | -0.00 | 0.15 | 0.17 |
| ANN | 10 | -20% | -0.09 | | -0.00 | | -0.05 | |
| | | -10% | -0.10 | | -0.00 | | 0.06 | |
| | | +10% | -0.12 | | -0.00 | | -0.45 | |
| | | +20% | -0.07 | | -0.00 | | -0.59 | |
| | | Average | -0.09 | | -0.00 | | | |
| X2 Standard | 11 | -10% | -0.06 | | -0.00 | | 0.07 | |
| | | -5% | -0.07 | | -0.00 | | 0.05 | |
| | | +5% | -0.05 | | -0.00 | | 0.20 | |
| | | +10% | -0.01 | | -0.00 | | -0.34 | |
| | | Average | -0.05 | | -0.00 | | | |
| Banks Pumping Limit | 12 | -5% | 0.07 | 0.48 | 0.00 | 0.00 | 2.63 | 0.96 |
| | | Average | 0.07 | 0.48 | 0.00 | 0.00 | 2.63 | 0.96 |

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| High Sensitivity | 0.2 < \|SI\| |
| Moderate Sensitivity | 0.1 <= \|SI\| <= 0.2 |
| Low Sensitivity | \|SI\| < 0.1 |

deliveries and better water quality with the guidance of the SI. Meanwhile, EI may be more helpful to modelers. Modelers may use EI to guide their refinement of data input as well as the model structure. Since the targeted audiences of this technical memorandum are mainly water planners, operators, water users, and managers, discussions will be focused more on SI unless where SI cannot be computed.

## 3 Study Result Discussions

In this section the impacts of selected input parameters on SWP deliveries are discussed one by one based on Table 1. All discussions and interpretations of SI and EI are based on the 73-year general trend, although for individual years the causes for SWP delivery changes may be different. Interested readers may request detailed model outputs from DWR Bay-Delta Office and find out exact cause of SWP delivery changes for any given year.

The entire Central Valley consists of many sub-water systems with various scales, such as Feather River system, American River system, etc. All these sub systems are interconnected in different ways. Any changes in one sub system may affect many other sub systems. The discussions at the level of details contained in this memorandum may only be limited to the major factors involved.

All discussions and interpretations are contained in the following table for convenience. The left-most column of the table lists all selected model input parameters for the analysis. For each input parameter, SI and/or EI values and associated discussions and interpretations for three output variables – SWP Delta Delivery, SWP NOD Delivery, and Article 21 Delivery are listed in three separate sub-rows. The first column from the left of each sub-row lists the row numbers that may be referenced by discussions of other input parameters/output variables.

| Input Parameter | Row # | SWP Deliveries | Average SI / EI | Impact | Discussions and Comments |
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| Shasta Inflow | 1 | SWP Delta Delivery | 0.04/0.08 | Low | SWP and CVP are bound up with each other through the Coordinated Operations Agreement (COA) between the Reclamation and DWR. More water available within CVP system means more water available to SWP through the preset distribution ratio in COA. |
| | 2 | SWP NOD Delivery | 0.00/0.00 | Low | Water delivered to NOD SWP contractors is from Feather River basin and Oroville Lake. It is not affected by the inflow changes to Shasta. |
| | 3 | Article 21 Delivery | 0.01/0.34 | Low | The increase of Shasta inflow will increase the Shasta winter spill. The increased Shasta winter spill will, in turn, make more water available in Delta for Article 21 Delivery.<br>EI of 0.034 is much greater than the SI of 0.01 in this case because of the magnitude of base Article 21 Delivery is much smaller than the Shasta inflow. Please refer to Section 4.1.1 of the *Main Report* for the detailed discussion on this topic. |
| Oroville Inflow | 4 | SWP Delta Delivery | 0.20/0.20 | High | The Oroville Lake storage, which has a high positive correlation with the Oroville inflow, is one of the most important factors in determining the amount of water available for SWP Delta delivery in the SWP delivery allocation procedure. When Oroville inflow increases, greater allocation decisions due to the higher Oroville storages will be made, which may lead to higher SWP Delta delivery. |
| | 5 | SWP NOD Delivery | 0.00/0.01 | Low | The major portion of NOD Delivery is for FRSA Settlement Contractors who has, in general, a higher priority of receiving SWP water delivery than other SWP contractors due to their water rights existed prior to SWP. The impacts of Oroville inflow changes (increase or decrease) on them are minimal. |
| | 6 | Article 21 Delivery | -0.02/-0.51 | Low | The negative SI and EI indicate that when Oroville inflow increases Article 21 delivery generally decreases. This situation is caused by the rules governing Article 21 delivery (see Section 4.1.3. of the *Main Report* for details). Article 21 delivery has a lower priority than SWP Delta delivery. The increase of Oroville inflow will increase the SWP Delta delivery. In turn, the increased SWP Delta delivery may reduce the conveyance capacity that can be used for Article 21 Delivery, and at the same time SWP San Luis storage may be used more aggressively, leaving less chance for the reservoir to be full. Therefore, Article |

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| | | | | | 21 delivery decreases with the increase in Oroville inflow.<br><br>When Oroville inflow decreases, lower Banks export (see row 10 of column 2 in Table 2 of the *Main Report*, SI = 0.18) and lower SWP Delta Delivery make more conveyance capacity available for Article 21 Delivery whenever there is surplus water in the Delta and SWP San Luis reservoir is full. |
| Yuba Inflow | 7 | SWP Delta Delivery | 0.12/0.07 | Medium | Yuba River inflow is considered uncontrolled local inflow in CalSim-II. It does not play a direct role in SWP allocation decision process. Instead, it is a supplemental source of water for SWP deliveries after allocation decision is made. It can affect SWP Delivery both directly and indirectly. After SWP allocation decision is made, the higher Yuba River inflow as an uncontrolled local inflow will be used first for SWP NOD Delivery, which, in turn, reduces the project release from Oroville. As a result, Oroville storage will be higher and it will have more water for SWP Delta Delivery. The higher Oroville storage may also make a higher delivery target in the following months. If Yuba River inflow is more than meeting the local demands, extra water can be used directly for the SWP Delta Delivery. |
| | 8 | SWP NOD Delivery | 0.00/0.00 | Low | The Yuba River inflow can be used first for the SWP NOD Delivery, however, because the major portion of SWP NOD Delivery, FRSA, has a higher priority of receiving SWP water delivery than other SWP contractors due to their water rights existed prior to SWP, Oroville release will be used first before being delivered to any other SWP Contractors for making up any FRSA shortages after local inflows are used up. Therefore, Yuba River inflow changes do not have a significant impact on SWP NOD Delivery. |
| | 9 | Article 21 Delivery | Non-monotonic SI and EI, see row 3 of column 3 of Table 1 for individual SI and EI | low | When Yuba River inflow increases, SI=0.01, as shown in row 3 of column 3 of Table 1, indicates that the Article 21 Delivery increases. This is because the increase of Yuba River inflow may make (1) more winter spill from Oroville due to the higher storage and (2) more Yuba River excess water for meeting local demands. In both cases more water at Delta is available for Article 21 Delivery.<br><br>When Yuba River inflow decreases, SI=-0.00 indicates that the Article 21 Delivery still increases, although not significant. This is because the decreased Yuba River inflow makes more Oroville release for meeting local demands and lower storage left in Oroville. The lower Oroville storage then generates a lower delivery target for SWP contractors for following months. In turn, lower delivery target makes more Delta surplus water and SWP |

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| | | | | | conveyance capacity available for Article 21 Delivery in some years. |
| Folsom Inflow | 10 | SWP Delta Delivery | 0.12/0.05 | Medium | Similar to Shasta inflow (row 1), SWP and CVP are bound up with each other through COA. More water available within CVP system means more water available to SWP through the preset distribution ratio in COA. |
| | 11 | SWP NOD Delivery | 0.00/0.00 | Low | Similar to Shasta inflow (row 2), water delivered to NOD SWP contractors is from Feather River basin and Oroville Lake. It is not affected by the inflow changes to Shasta. |
| | 12 | Article 21 Delivery | 0.02/0.16 | Low | Similar to Shasta inflow (row 3), the increase of Folsom inflow may increase the Folsom winter spill. The increased Folsom winter spill may, in turn, make more water available in Delta for Article 21 Delivery. |
| Projected Land Use | 13 | SWP Delta Delivery | -0.04/-0.09 | Low | The Projected Land Use was used to calculate the projected local water supply (see Section 3.2.3.2 of the *Main Report* for more details). The unit of the Projected Land Use is in acres and it cannot be used to compute SI directly. A new term that combines both diversion requirement and local water supply changes may be defined to reasonably represent the total water volume changes due to changes in the Projected Land Use. The new term is [diversion requirement (DR) – local water supply (I-D)], which may be considered as the “net diversion requirement” for surface water diversion and groundwater pumping beyond local water supply. The SI of the Projected Land Use can then be computed based on “net diversion requirement” (see Section 4.2 of the *Main Report* for the detailed discussion on the “net diversion requirement” and calculation of SI). In CalSim-II, land use based demand (diversion requirement) and local water supply calculations are only applied to Sacramento Valley.<br><br>The negative sign of SI and EI mean that the “net diversion requirement” which is used to compute SI and EI changes in the opposite direction of SWP Delta Delivery. In other words, the increased Projected Land Use makes the local water supply decrease. The decreased local water supply means less uncontrolled local water for SWP NOD Delivery, which, in turn, increases the project release from Oroville. As a result, Oroville storage will be lower and it will have less water for SWP Delta Delivery. The lower Oroville storage may also make a lower delivery target in the following months. Please refer to Section 4.5 of the *Main Report* for more discussion. |
| | 14 | SWP NOD | 0.02/0.17 | Low | The increase of Project Land Use is equivalent to increase the NOD water |

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| | | Delivery | | | demand (larger diversion requirement and less local water supply). Since the NOD SWP and CVP have higher priorities in deliveries, higher water demands mean that more project water is delivered to NOD. |
| | 15 | Article 21 Delivery | -0.01/-0.45 | Low | The increased SWP NOD Delivery makes less water available for Article 21 Delivery. |
| SWP Delivery-Carryover Curve | 16 | SWP Delta Delivery | /-0.02 | n/a | In CalSim-II, a user-defined delivery versus carryover risk curve is used to estimate the target delivery and carryover storage from the total estimated water available for a year. Section 3.3.1 of the *Main Report* contains the detailed discussion of the delivery versus carryover risk curve. In this sensitivity study, the 20% increase of delivery versus carryover risk curve means that for a given delivery, 20% more carryover storage should be reserved as shown in Figure 7 of the *Main Report*.<br><br>There are no SI values computed for SWP Delivery-Carryover Curve since relevant water volume changes cannot be properly defined and computed.<br><br>When the carryover storage increases, the SWP delivery target drops given the same amount of water available for that year, which leads to the decreased SWP Delta Delivery. |
| | 17 | SWP NOD Delivery | /0.00 | n/a | SWP NOD Delivery has two components – FRSA and Table A deliveries. FRSA delivery, which is the major portion of SWP NOD Delivery, is subject to a separate allocation rule than the Table A delivery (to Butte County and Yuba City). Due to the relatively small magnitude, the impact of delivery and carryover risk curve change on the total SWP NOD Delivery is not significant. |
| | 18 | Article 21 Delivery | /0.08 | n/a | The decreased SWP Delta Delivery and increased Oroville storage due to the carryover storage increase may make more Oroville winter spill and more conveyance capacity available for the Article 21 Delivery. |
| SWP San Luis Rule Curve | 19 | SWP Delta Delivery | Non-monotonic EI, see row 7 of column 1 of Table 1 for individual EI | n/a | SWP San Luis Rule Curve was developed by CalSim-II modelers and used as the guidance of SWP San Luis reservoir operation. It was discussed in details in Section 3.3.2 of the *Main Report*. As shown in Figure 8 of the *Main Report*, the increase of the rule curve means the entire curve is increased by a certain percentage uniformly subject to the limit of the top of conservation pool. Similarly, the decrease of the rule curve means the entire curve is decreased by a certain percentage uniformly subject to the limit of the bottom of conservation pool. |

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| | | | | | There are no SI values computed for SWP San Luis Rule Curve since relevant water volume changes cannot be properly defined and computed.<br><br>The changes of SWP San Luis Rule Curve have a mixed (non-monotonic) impact on the SWP Delta Delivery. When the rule curve increases, more water needs to stay in the San Luis Reservoir in both filling and emptying periods. In other words, more water should be pumped into the reservoir in the filling period and less water can be released from the reservoir in order to keep a higher storage target during the emptying period. In both periods, less water can be available for SWP Delta Delivery.<br><br>When the rule curve decreases, less water will be pumped into the San Luis Reservoir in the filling period and, as a result, less water can be available for SWP Delta Delivery during the emptying period. |
| | 20 | SWP NOD Delivery | Non-monotonic EI, see row 7 of column 2 of Table 1 for individual EI | n/a | As discussed in row 17, SWP NOD Delivery has two components – FRSA and Table A deliveries (to Butte County and Yuba City). FRSA delivery, which is the major portion of SWP NOD Delivery, is subject to a separate allocation rule than the Table A delivery. The NOD Table A delivery follows the same allocation procedure as SWP Delta Delivery. Therefore it has the same responses to San Luis Rule Curve changes as SWP Delta Delivery. Due to the relatively small magnitude, the impact of San Luis Rule Curve change on the total SWP NOD Delivery is not significant. |
| | 21 | Article 21 Delivery | /0.46 | n/a | As discussed in row 19, when the rule curve increases, San Luis reservoir always keeps higher storages throughout a year. The higher year-round reservoir storage makes reservoir full more frequent, in which case more Article 21 Delivery may be made. |
| SWP Table A Demand | 22 | SWP Delta Delivery | 0.47/0.55 | High | SWP operation is all about delivering water to meet contractors' demands. Twenty-nine agencies have contracts for long-term water supply from SWP totaling about 4.15 million acre-feet annually, of which about 4.05 million acre-feet are for contracting agencies with service areas south of the Sacramento-San Joaquin Delta. In this sensitivity study, the base SWP demand is set at 3.5 million acre-feet and it vary from 2.5 to 4.5 million acre-feet. Within this given range of variation, the demand appears to dominate the entire SWP operation. In other words, the SWP operation is demand-driven. For every acre-foot increase of SWP demand, SWP Delta Delivery increases by approximately half acre-foot. |

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| | 23 | SWP NOD Delivery | 0.00/-0.01 | Low | Since the magnitude of NOD Table A demand is negligible comparing to either the NOD FRSA demand or SWP Delta Delivery, the impact of SWP Table A Demand changes on SWP NOD Delivery is insignificant. |
| | 24 | Article 21 Delivery | -0.11/-2.62 | Medium | When SWP Table A Demand increases, more SWP Delta Delivery may (1) take up more conveyance capacity; (2) need a more aggressive operation of SWP San Luis Reservoir which leaves less chance for the reservoir to be full; and (3) less surplus water available in the Sacramento-San Joaquin Delta. Therefore, Article 21 Delivery decreases. |
| Article 21 Demand | 25 | SWP Delta Delivery | -0.01/0.00 | Low | "Article 21" water is contractor requested water that may only be provided from Delta surplus water and only to SWP contractors requesting it. Detailed discussion of Article 21 Delivery is contained in Sections 3.3.3.2 and 4.1.3 of the *Main Report*. From the discussion it may be found that the Article 21 delivery can only be made when the following three conditions are met at the same time: (1) There is surplus water available in the Delta; (2) The SWP portion of the San Luis reservoir is full; and (3) There is conveyance capacity available. Therefore, Article 21 Delivery has a lower priority than the SWP Delta Delivery and consequently its demand changes can affect little on the SWP Delta Delivery. |
| | 26 | SWP NOD Delivery | 0.00/0.00 | Low | Similar to SWP Delta Delivery, Article 21 Demand changes have little impact on SWP NOD Delivery due to its low priority. |
| | 27 | Article 21 Delivery | 0.17/0.15 | Medium | If three criteria discussed in row 25 are met, Article 21 Delivery can be made up to its demand. Therefore, when the Article 21 demand increases, the Article 21 Delivery can be increased. |
| ANN | 28 | SWP Delta Delivery | /-0.09 | n/a | The Artificial Neural Network (ANN) was developed by DWR in 1999, which tries to mimic the flow-salinity relationships as modeled in DSM2, but provide a rapid transformation of this information into a form usable by CalSim-II model. The ANN is implemented in CalSim-II to constrain the operations of the upstream reservoirs and the Delta export pumps in order to satisfy particular salinity requirements. The detailed discussion of how the ANN is used in CalSim-II may be found in Section 3.4.1 of the *Main Report*.<br><br>There are no SI values computed for ANN since relevant water volume changes cannot be properly defined and computed.<br><br>In this study, the increase of ANN means that the ANN overestimates the |

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| | | | | | salinity (EC) with a given set of Delta inflows and exports. If the estimated Delta salinity (EC) by ANN is above the Delta salinity standards, more Delta inflow may be required for maintaining the Delta salinity standards and Delta export may be reduced and as a result, SWP Delta Delivery decreases. |
| | 29 | SWP NOD Delivery | /0.00 | n/a | The Delta salinity standard is one of the major controls of Delta Export. However, NOD Delivery which occurs upstream of the Delta is not significantly impacted by the ANN changes. |
| | 30 | Article 21 Delivery | Non-monotonic EI, see row 10 of column 3 of Table 1 for individual EI | n/a | Exports respond directly to changes in salinity. When salinity was reduced by 10% or 20%, ANN constraints were relaxed and SWP exports were increased accordingly. Likewise, sum of SWP Delta Delivery and Article 21 increased with exports. However, the division of deliveries between SWP Delta Delivery and Article 21 is only indirectly influenced by changes in salinity. Relaxation of ANN constraints could lead to higher NOD storage which in turn boosts SWP Delta Delivery allocations which may result in less opportunity for Article 21 delivery – a combination of full San Luis, available delivery capacity, and available Delta surplus. This could then result in overall higher deliveries – all increases being with SWP Delta Delivery and a slight decrease in Article 21. This is what appears to have happened when salinity was reduced by 10%. When salinity was reduced by 20%, sum of SWP Delta Delivery and Article 21 increased as expected, but in this case both SWP Delta Delivery and Article 21 were increased. It is important to note that in both cases the changes in Article 21 were small. In the case of the 10% decrease in salinity, Article 21 deliveries were reduced by less than 0.06%. With a 20% decrease in salinity, Article 21 deliveries increased by less than 0.05%. An appropriate explanation is that Article 21 Delivery is insensitive to decreases in salinity and that the change in sign in the elasticity index is more an indication of the dynamic non-linearity of the SWP delivery allocation process. |
| X2 Standard | 31 | SWP Delta Delivery | /-0.05 | n/a | X2 is the distance in kilometers from the Golden Gate Bridge to where the average daily salinity is 2 parts per thousand. The 1995 Water Quality Control Plan (WQCP) established the minimum number of days during February to June that the salinity measured in electrical conductivity at Chipps Island and Roe Island has to be maintained at 2.64 mmhos/cm or lower. The Kimmerer-Monismith equation is used to calculate outflow required (in cfs) to maintain the EC standard (average monthly position in kilometers). The Kimmerer-Monismith equation is algebraically reversed and solved to obtain the Delta outflow required for the current month to have the X2 line at the required location (see Section 3.4.2 of the *Main Report* for details). In this |

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| | | | | | study, the sensitivity analysis is designed to vary the left-hand side of the reversed Kimmerer-Monismith equation, which is the required Delta outflow for maintaining the given EC position, by ± 5 percent and ± 10 percent subject to the maximum required monthly outflows at all three locations. The increase of X2 standard means that the required Delta outflow for maintaining the given EC position is overestimated. In other word, when X2 standard increases, more water is required to maintain the Delta X2 standard and therefore, less water can be available for SWP Delta Delivery.<br><br>There are no SI values computed for X2 since relevant water volume changes cannot be properly defined and computed. |
| | 32 | SWP NOD Delivery | /0.00 | n/a | Similar to row 29, the Delta X2 standard is one of the major controls of Delta Export. However, NOD Delivery which occurs upstream of the Delta is not significantly impacted by the Delta X2 standard changes. |
| | 33 | Article 21 Delivery | Non-monotonic EI, see row 11 of column 3 of Table 1 for individual EI | n/a | Similar to the discussion for ANN (see row 30), the SWP exports (i.e. sum of SWP Delta Delivery and Article 21 Delivery) have a negative correlation with the changes in X2 standard. When X2 standard increases (i.e. the required Delta outflow for maintaining the given EC position is overestimated), the SWP exports decrease; and when X2 standard decreases the SWP Delta exports increase (see row 12 of column 20 in Table 2 of the *Main Report*).<br><br>The division of deliveries between SWP Delta Delivery and Article 21 Delivery is only indirectly influenced by changes in X2 constraint. Because of the dynamic non-linearity of the SWP delivery allocation process, depending on specific year type sequences, within-year hydrologic distributions, and the magnitudes of X2 constraint changes, the following four possible scenarios can occur: (1) both SWP Delta Delivery and Article 21 Delivery increase simultaneously when the total SWP exports increase; (2) both SWP Delta Delivery and Article 21 Delivery decrease simultaneously when the total SWP exports decrease; (3) while reducing the SWP exports (i.e. sum of SWP Delta Delivery and Article 21 Delivery), the increase of X2 constraint could lead to lower NOD storage which in turn reduces SWP Delta Delivery allocations which may result in more opportunity for Article 21 delivery – a combination of the level of San Luis storage, available delivery capacity, and available Delta surplus; and (4) while increasing the SWP exports, the relaxation of X2 constraint could lead to higher NOD storage which in turn increases SWP Delta Delivery allocations which may result in less opportunity for Article 21 delivery – again, a combination of the level of San Luis storage, available |

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| | | | | | delivery capacity, and available Delta surplus.<br><br>In this particular study, when X2 standard increases by 5% or decreases by 5% and 10%, scenario (3) or (4) above dominate; and when X2 standard increases by 10%, scenario (2) takes the major effort (see row 11 of column 3 in Table 1). |
| Banks Pumping Limit | 34 | SWP Delta Delivery | 0.48/0.07 | High | The Banks Pumping Plant was completed in 1969 and expanded by adding four more pumps in 1986. The Banks Pumping Plant is able to pump about 10,300 cfs. However, under SWRCB D-1485 and the U.S. Army Corps of Engineers permit (public notice 5820A, amended), Banks Pumping Plant capacity is restricted at a mean monthly pumping rate of 6,680 cfs. From December 15 to March 15, the average monthly pumping rate can be increased up to 8,500 cfs if San Joaquin flow at Vernalis exceeds 1,000 cfs.<br><br>In the real-time operation of the Banks Pumping Plant, however, the pumping may not reach its scheduled limits due to the following two reasons: (1) Weeds accumulation in front of the trash rack of the Skinner Fish Facility could retard flows reaching the pumps while they are allowed to pump water at their permitted capacity; and (2) Low energy tide from the San Francisco Bay could prevent water from flowing into the Clifton Court Forebay fast enough to feed the pumps while they are allowed to pump water at their permitted capacity.<br><br>Based on discussions with SWP Operations Control Office staff, the sensitivity analysis for Banks pumping capacity is designed to reduce the permitted capacity of 6,680 cfs for the period of March 15 through December 15 by 5 percent (334 cfs). The Sensitivity Index (SI) for various output variables will be computed by dividing their annual volume changes by the equivalent volume change of the monthly pumping capacity.<br><br>The changes of Banks pumping limits have large and direct impact on SWP Delta export ability. When Banks pumping limits decrease, SWP Delta export decreases and, in turn, SWP Delta Delivery decreases. |
| | 35 | SWP NOD Delivery | 0.00/0.00 | Low | The decrease of Banks pumping limits only affects the SWP Delta export and delivery ability. SWP NOD Delivery which occurs upstream of the Delta is not affected. |
| | 36 | Article 21 Delivery | 0.96/2.63 | High | The decrease of Banks pumping limits will reduce the chance of having extra conveyance capacity available for Article 21 Delivery. |

# 4 Alternative Presentations of Results

### 1. Pareto Chart

For the convenience of comparing impacts of model input parameters on SWP deliveries, this section summarizes sensitivities of SWP deliveries (SWP Delta Delivery, SWP NOD Delivery, and Article 21 Delivery) with respect to model input parameters analyzed. As shown in Figure 1, sensitivity indices (SI) for input parameters whose monotonic SI values can be computed with respect to SWP Delta Delivery are sorted and plotted together in a single chart which is called Pareto Chart. From the chart it can be found that the Banks Pumping Limit has the largest impact on the SWP Delta Delivery, i.e. when Banks Pumping Limit decreases by one thousand-acre-feet (TAF), SWP Delta Delivery will decrease by 0.48 TAF. SWP Table A Demand has the next largest impact on SWP Delta Delivery, or for every TAF increase or decrease of the SWP Table A Demand, SWP Delta Delivery will increase or decrease by 0.47 TAF. Projected Land Use has the largest negative impact on SWP Delta Delivery, i.e. for every equivalent TAF ("net diversion requirement") increase or decrease of Projected Land Use, SWP Delta Delivery will decrease or increase by 0.09 TAF. Article 21 Demand has the least impact on SWP Delta Delivery.

The elasticity indices (EI) for input parameters whose monotonic EI values can be computed with respect to SWP Delta Delivery are sorted and plotted together in a single chart in Figure 2. From the Figure 2, SWP Table A Demand, again, is found to be most elastic with respect to SWP Delta Delivery, i.e., when SWP Table A Demand increases or decreases by one percent, SWP Delta Delivery will increase or decrease by 0.55 percent. Oroville Inflow is the next most elastic with respect to SWP Delivery, or when Oroville Inflow increases or decreases by one percent, SWP Delta Delivery will increase or decrease by 0.26 percent. ANN is the most elastic with respect to SWP Delta Delivery in opposite direction, i.e. for every percent increase or decrease of ANN, SWP Delta Delivery will decrease or increase by 0.09. Article 21 Demand has the least inelastic with respect to SWP Delta Delivery.

Similar to Figures 1 and 2, Figures 3 and 4 and Figures 5 and 6 are comparisons of SIs and EIs for SWP NOD Delivery and Article 21 Delivery, respectively. Interested readers may draw their own conclusions from those figures using the similar method described in previous two paragraphs.

### 2. Spider Plot

There are situations that model output variables have significant non-linear responses to the input parameter changes, in which case the average SI and/or EI may not accurately represent the true sensitivity and/or elasticity of output variables in response to input parameters and ideally evaluation for each individual SI and/or EI should be conducted. However, as stated in Section 2.2 of the *Main Report*, in the study at the current level of detail, only the average monotonic SI or EI were evaluated.

In this supplemental technical memorandum, attempt is made to explore the SWP deliveries in response to Table A Demand and Article 21 Demand changes in further details through Spider Chart. Figure 7 contains SWP delivery volume changes in response to Table A Demand changes. From the figure, readers may be able to have the following observations when Table A Demand changes within the range of 2500-4500 TAF/Year: (1) SWP Delta Delivery changes monotonically in the same direction with Table A Demand changes; (2) SWP Delta Delivery is not linearly responding to Table A Demand changes; (3) SWP NOD Delivery is not significantly affected by the Table A Demand changes; (4) Article 21 Delivery changes monotonically in the opposite direction with Table A Demand changes; (5) Article 21 Delivery is not linearly responding to Table A Demand changes; and (6) The magnitude of SWP Delta Delivery changes is much larger than that of Article 21 Delivery.

Similar to Figure 7, Figure 8 contains SWP delivery volume changes in response to Article 21 Demand changes. Among many others, two major observations may worth noting from this figure: (1) Only Article 21 Delivery is significantly affected by the changes of Article 21 Demand in peak months (December-March). The impact of the Article 21 Demand changes on SWP Delta Delivery and SWP NOD Delivery may be negligible and (2) The Article 21 Delivery increases significantly when Article 21 Demand in peak months increases from 134 (base value) to approximately 400 TAF/month. When Article 21 Demand in peak months continue to increase beyond 400 TAF/month, the increase of Article 21 Delivery becomes less significant.

In order for a Spider Chart to be more meaningful, multiple (say, more than two) ranges of changes of model input parameters need to be assigned and model responses need to be generated accordingly. In our current sensitivity analysis, multiple ranges of changes were only assigned to a limited number of model input parameters. In other words, Spider Chart may only applied to model input parameters to which multiple ranges of changes were assigned.

**Figure 1**
**Summary of Sensitivity Index for SWP Delta Delivery**

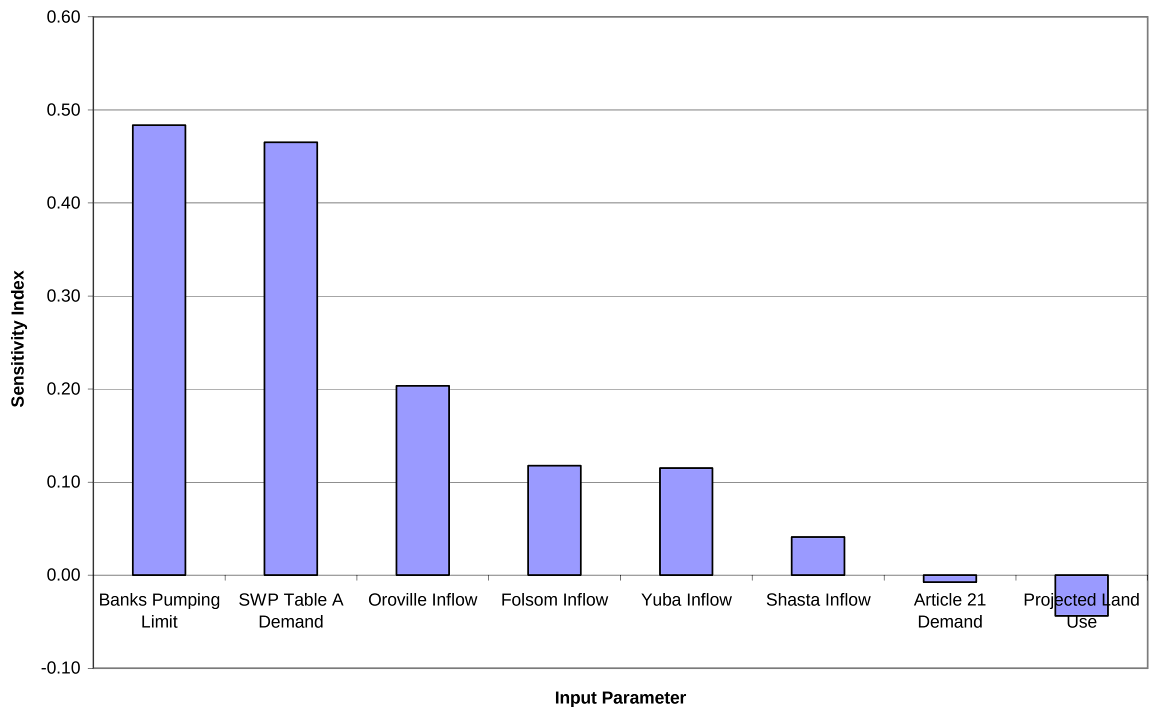


**Figure 2**
**Summary of Elasticity Index for SWP Delta Delivery**

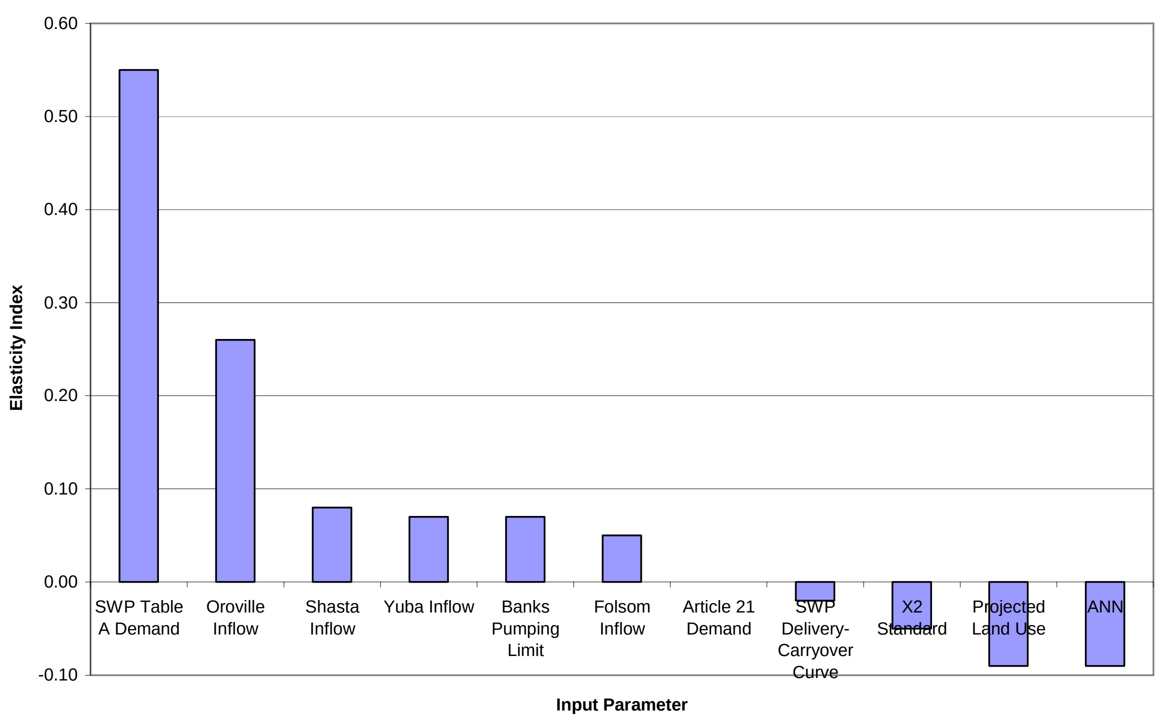

**Figure 3**
**Summary of Sensitivity Index for SWP NOD Delivery**

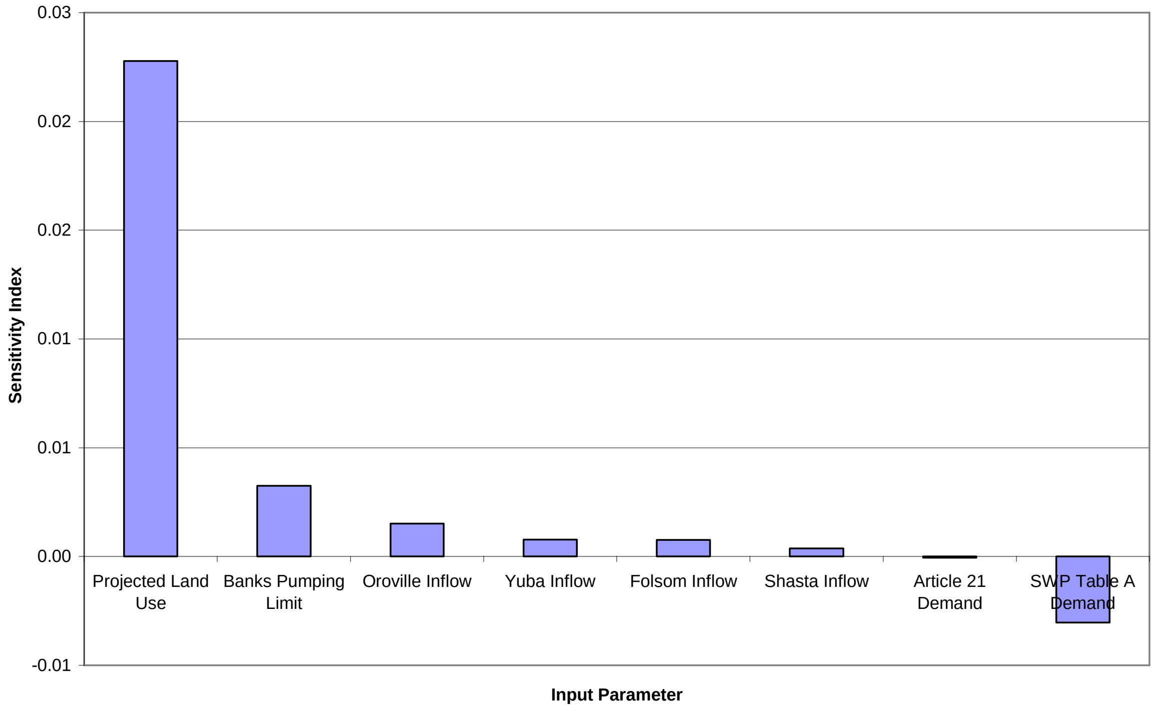


**Figure 4**
**Summary of Elasticity Index for SWP NOD Delivery**

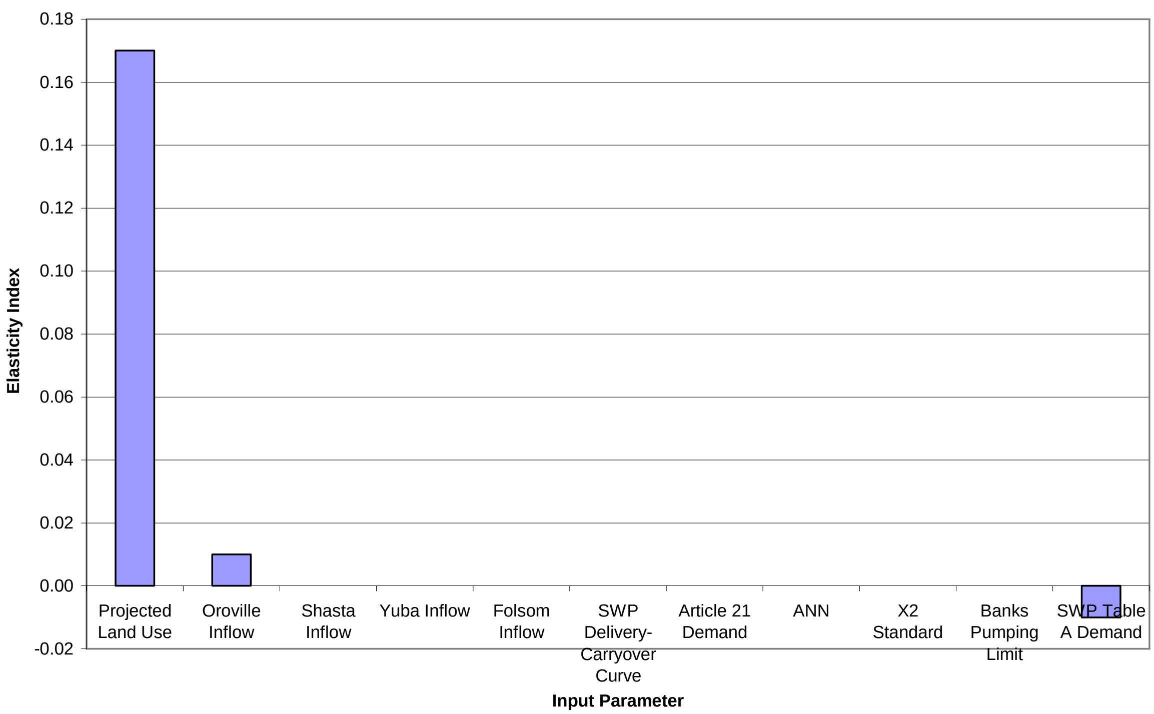

**Figure 5**
**Summary of Sensitivity Index for Article 21 Delivery**

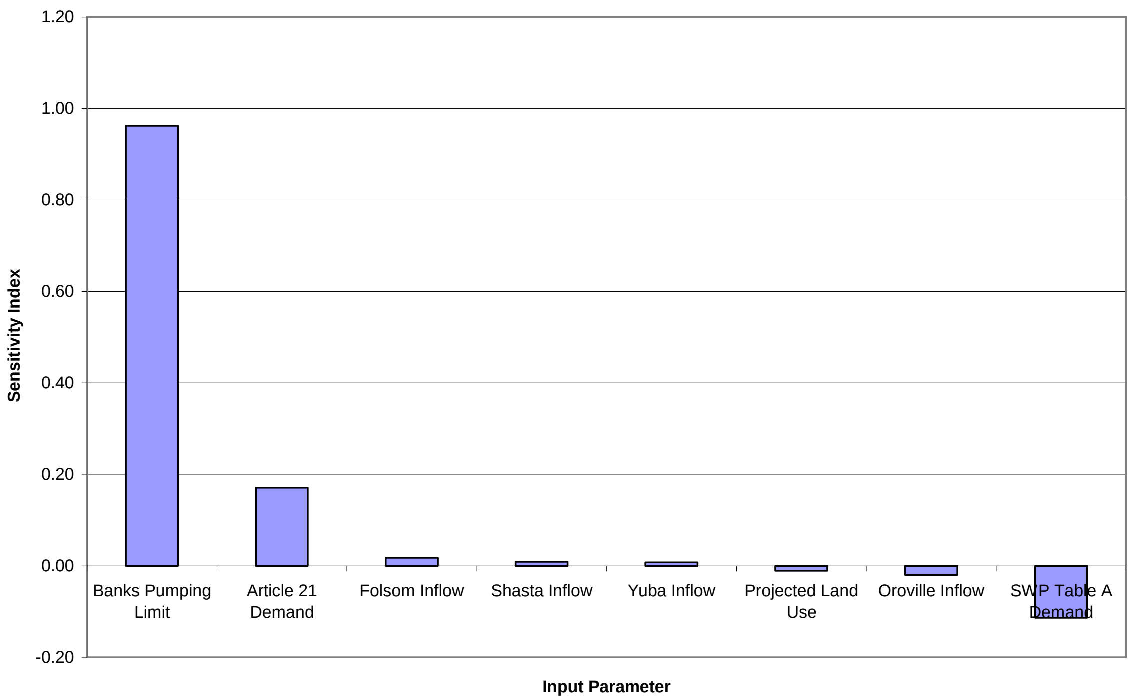


**Figure 6**
**Summary of Elasticity Index for Article 21 Delivery**

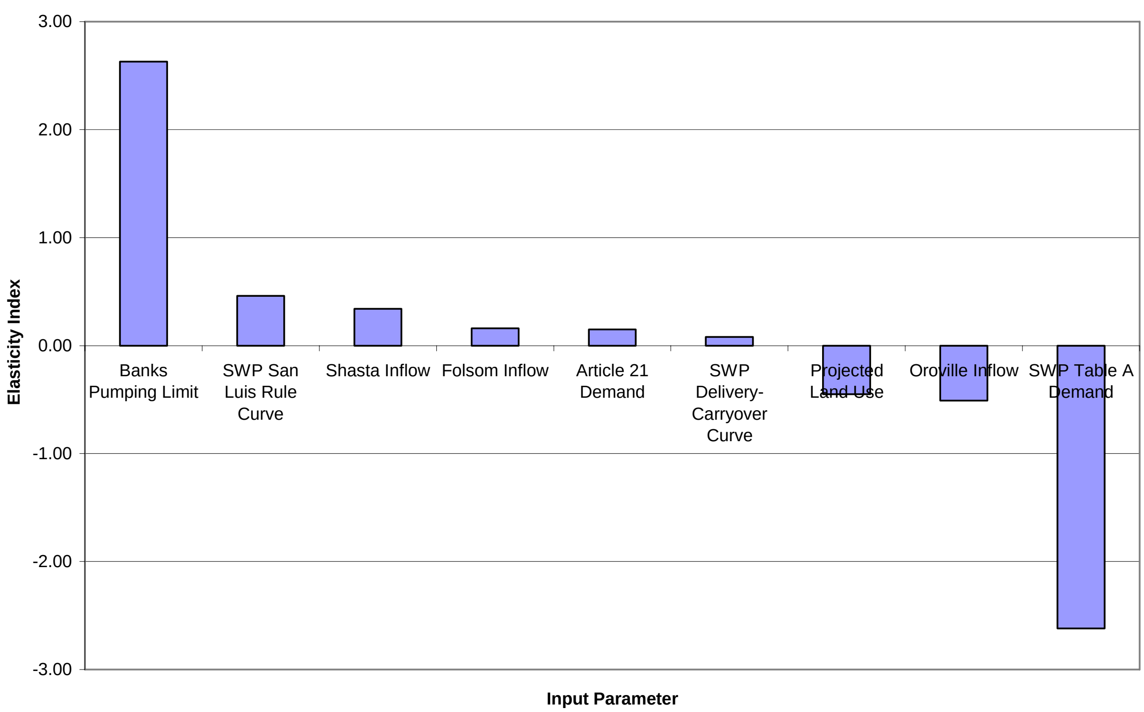

**Figure 7**
**SWP Deliveries vs. Table A Demand**


**Figure 8**
**SWP Deliveries vs. Article 21 Demand**